WLTAE: An HLA Federation for Logistics and Warfighting Models

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Keywords:
Logistics, Warfighting, TPFDD, ELIST, THUNDER, HLA,
[1]Advanced Logistics Program, simulation interoperability, HLA Federation Class

Abstract: *The Warfighting and Logistics Technology and Assessment Environment (WLTAE) is intended to dynamically link warfighting and logistics models in a HLA-compliant simulation. WLTAE is currently funded as part of the DARPA Advanced Logistics Program (ALP) and will provide proactive planning and trade-off analysis capabilities for logistics in terms of the warfighting impact. The simulation currently has three federates: a warfighting federate, represented by the THUNDER model, a logistics federate, represented by the Enhanced Logistics Intratheater Support Tool (ELIST), and a Viewer/Controller federate. The Federation Object Model (FOM) is based on the Time-Phased Force Deployment Data (TPFDD) representation, facilitating the inclusion of additional logistics and warfighting models into the simulation. The WLTAE federates use the HLA Foundation Class library, a C++ library providing a object-oriented framework for rapid federate development. This paper discusses the general logistics-warfighting FOM used in WLTAE, the implementation process, and the information displays used to monitor and control the simulation*

1. Introduction

Warfighting and logistics models and analyses have generally not been closely linked to one another for a variety of reasons. Typically, warfighting models have been run to examine weapons and strategies, and logistics limitations have not been a major concern. On the other hand, logistics models have been typically run in a scheduling mode to see if the time phased force

Approved for Public Release, Distribution Unlimited deployment data (TPFDD) schedules desired by the CINC can be realistically achieved. There has not been much concern about the likelihood of enemy attacks on the logistics infrastructure. Additionally, sufficient supplies have been sent in the past to handle most warfighting contingencies, so the logistics models have not had to respond quickly to warfighting variations.

As a result, there is no truly integrated model that can be used to develop and test an integrated warfighting and logistics plan. Several developments since the end of the Cold War make this situation unacceptable. First, there has been considerable discussion in DoD about cutting back on the logistics infrastructure and moving more in the direction of a "just-in-time" logistics strategy [1]. With the proliferation of theater ballistic missiles and other advanced weapons, there is an increasing vulnerability of the logistics systems to enemy attack. The assumptions that planned logistics supplies will be sufficient to handle all warfighting contingencies and that the enemy will not attack the logistics infrastructure are no longer valid.

1.1 What is the Warfighting Logistics Technology and Assessment Environment (WLTAE)

WLTAE is being developed to help meet this need for integrated warfighting/logistics models. WLTAE is intended to provide a flexible interface that will allow the user to dynamically link warfighting and logistics models and data bases in order to evaluate alternative operational plans and examine new logistics strategies. Dynamic linking will be two-way; logistics shortfalls will impact the warfighting simulation, while the logistics infrastructure will be present as targets in the warfighting model, allowing the enemy to attack the logistics laydown.

WLTAE will be an HLA federation to facilitate model inter-operability and to support the transition to the next generation models such as the Joint Warfighting Simulation (JWARS). However, since few models are currently HLA compliant, WLTAE started by using non-HLA legacy models and exchanging data between those models through a HLA federation.

1.2 Current WLTAE Federation

The current WLTAE federation consists of three federates. Since the goal was to link warfighting and logistics models, major theater-level warfare (MTW) was chosen as the warfighting scenario to ensure the logistics supply system was stressed. After surveying available warfighting models, the THUNDER model was selected for the warfighting federate to demonstrate proof-of-principle for the WLTAE concept. THUNDER models air warfare stochastically and ground warfare deterministically and is maintained by the Air Force Studies and Analysis Agency (AFSAA).

The matching logistics federate was then required to support flow of supplies and equipment forward from the sea and air ports of debarkation (SPODs and APODs, respectively) to the air and ground combat units in THUNDER. After surveying a number of logistics models, the Enhanced Logistics Intra-Theater Support Tool (ELIST) was selected for the logistics federate for the proof-of-principle demonstration. ELIST is maintained by the Military Transportation Management Command Transportation Engineering Agency (MTMC-TEA).

During earlier work in FY-97, a direct, non-HLA link between THUNDER and ELIST was developed by the Logistics Management Institute (LMI) as part of the WLTAE project. The current work in FY-98 has concentrated on converting this direct, non-HLA link into a general warfighting/logistics HLA federation that can include a variety of other models. As part of this conversion, a Viewer/Controller federate was developed to allow the user to observe the conduct of the simulation and to allow redirecting the flow of supplies and equipment as the warfight progresses.

1.3 Relation to the DARPA Advanced Logistics Program (ALP)

WLTAE is currently funded as part of the DARPA ALP. ALP is a five year program, running to 2001, with the objective of designing, developing and demonstrating an end-to-end prototype system using advanced technologies to realize efficient, real-time control of the logistics pipeline to put the right material in the right place at the right time to support the warfighting commands. Specific goals of ALP include: (1) a capability for automated logistics planning, (2) real-time situation assessment, and (3) end-to-end movement control with continuous monitoring techniques.

By linking logistics with warfighting models, WLTAE provides ALP with a proactive planning capability, allowing the likelihood and consequences of successful enemy attack against the logistics infrastructure to be assessed and incorporate contingencies into the logistics plan. WLTAE also provides a trade-off analysis capability. If the ALP plans cannot meet all of the CINC's requests, the warfighting simulation can be run with several logistics alternatives to help identify the most important items to be delivered. In turn, the ALP planning modules can serve as logistics models in their own right in WLTAE, with their automatic planning capability providing a dynamic link to the changing requirements of the warfighting simulation.

In this operating mode, the near-term user community for WLTAE is considered to be the CINCs and their staffs. WLTAE would serve as a mission planning tool, allowing them to analyze branches and sequels to their basic warfighting/logistics plan. In the longer term, planners are also seen as users of WLTAE. In a planning mode, alternate logistics concepts and systems could be designed and tested in WLTAE simulations to help determine how well these systems and concepts support the warfighters.

2. Linking Warfighting and Logistics Models

There are two challenges in linking warfighting and logistics models in WLTAE. The first challenge is an operational one of linking legacy models that were never designed to operate together or in a HLA environment. The second challenge is a more fundamental one of relating the entities and interactions that are important in a logistics environment to those that are important in a warfighting environment. Both of these issues are discussed briefly in the following sections.

2.1 Linking legacy models in a HLA environment

Most legacy warfighting and logistics models are designed to run in a stand-alone mode to completion of some fixed time step, typically on the order of several hours up to a day or more in simulation time, before they pause to write output or read new input. To try to exchange data on time steps smaller than these programmed time steps requires substantial source coding changes, raising multiple verification and validation issues. To avoid this problem, the WLTAE project restricted its attention to legacy models that were designed to run in a start-stop mode and could be re-started by command line code rather than through a user interface. Since logistics delivery times are on the order of hours, programs that had time increments in the range of 8 to 24 hours were considered acceptable.

Dynamic linking of logistics and warfighting models requires the models have some functionality in common. For example, the warfighting model has to have some logistics input such as unit status and weapon and fuel quantities, which would impact mission planning or conduct in the warfighting model. In turn, the logistics model has to have the ability to modify infrastructure parameters like port throughput, allowing damage assessments from the warfighting model against logistics targets to actually impact the subsequent delivery of supplies. Given this common functionality, it was fairly easy to dynamically link the legacy models by exchanging data when the models pause between time steps. This approach also avoided major validation and verification issues since any source code changes were then primarily associated with data and warfighting unit initializations at the simulation start-up time. We found that a number of other warfighting and logistics legacy models also have this type of interactive capability; consequently, the current WLTAE system is not limited to THUNDER and ELIST.

2.2 Linking the Logistics and Warfighting Scenario Environments

A more challenging problem is the general linking of the logistics and warfighting scenario environments. The logistics environment is detail-rich, with a TPFDD containing thousands of entries for all types of supplies, equipment and personnel flowing into the theater. The TPFDD also includes detailed schedule and routing data. Typically, a fighter squadron might be described in the TPFDD by 50 to 100 separate unit line number (ULN) items, representing the fighter aircraft, repair crews, weapons, spare fuel tanks, military police, meteorological teams, etc. All of these ULNs are required for the squadron to be fully operational.

Warfighting models typically have a much higher level of representation for warfighting units. For example, a warfighting model may describe a squadron in terms of only a few basic logistics descriptions, such as the number of aircraft and quantities of weapons and fuel.

The approach used in the current HLA linkage was an adaptation of the force module linkage used in the original non-HLA link between THUNDER and ELIST. The basic concept is shown in the next two figures. The TPFDD is used to drive ELIST, effectively assuming that everything arrives at the SPOD or APOD as scheduled in the TPFDD. ELIST then transports these items forward to a final destination specified in the TPFDD. In calculating the transportation flow, ELIST breaks each ULN up into a mixture of 17 commodity classes, shown in the list on the left side of Figure 1.

As shown in Figure 1, a particular ULN may have only a few of these 17 possible classes to transport. For example, a ULN labeled FAAA may represent the 18 F16 fighters in a fighter squadron. In addition to the fighters which fly directly to the final airbase, ELIST has to transport some quantity of "containerized" material, some number of "personnel" and quantities of "hazardous not-containerized" and "not-containerized." When all personnel have arrived and all amounts of the material have been delivered, the ULN is considered complete. A similar procedure is used for non-unit supplies such as fuel and water.

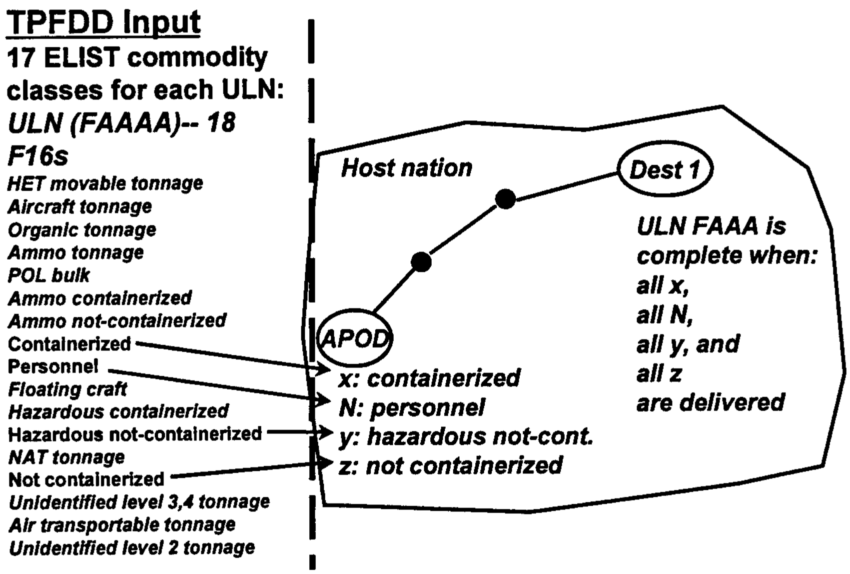

Figure 1 ELIST Transportation Methodology

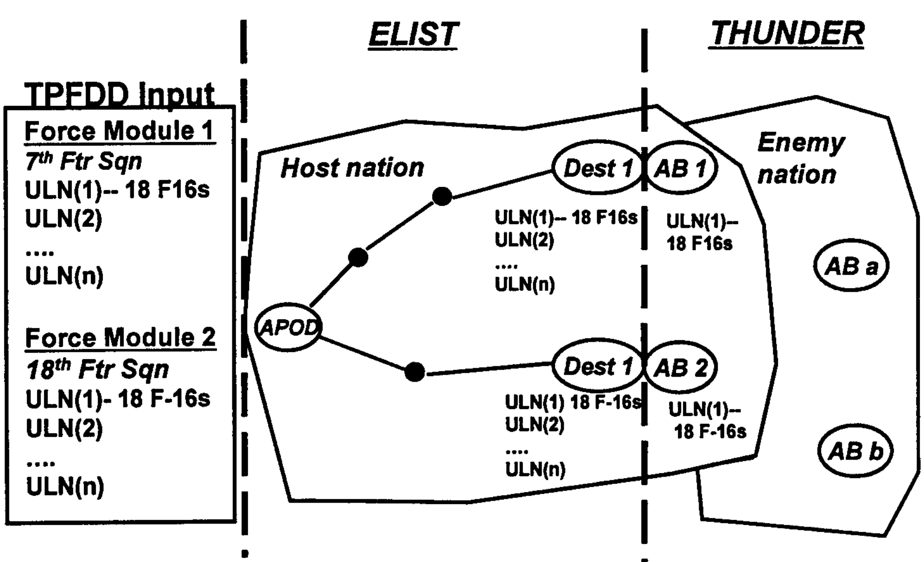

Figure 2 THUNDER-ELIST Force Module Linkage

Figure 2 illustrates the basic force module linkage between THUNDER and ELIST. Each force module in the TPFDD represents a fighting unit such as the 7th fighter squadron. This squadron might have 30 separate ULNs, the first of which was the ULN labeled FAAAA shown in Figure 1 with the actual fighter aircraft. All of these ULNs must arrive at the destination for the squadron to be fully operational, with all service kits, etc. Each ULN is considered complete following the process illustrated in Figure 1; when all ULNs making up that force module are complete, that fighter squadron can be transferred from the destination in ELIST to the airbase in THUNDER. A similar process is followed for each force module in the TPFDD.

3. HLA Federation for WLTAE

There are currently three federates which participate in the WLTAE federation: (1) ELIST (intra-theater logistics), (2) THUNDER (theater warfighting) and (3) Viewer/Controller (data logger and simulation interface)

The ELIST and THUNDER federates are both constructed around legacy models. All three federates rely heavily upon the HLA Foundation Class (HFC) library developed at APL. The HFC library provides a layer of abstraction between the simulation models and the intricacies of the HLA/RTI. The HFC includes the necessary framework of a federate, such as the federate ambassador, simulation driver, event services, time management, and automated attribute updating. Using the HFC considerably expedites federation development by minimizing source code duplication from federate to federate. The HFC library is described in further detail in [2].

Figure 3 shows the hierarchy of object classes, and the attributes associated with each class. The subclasses of organization and installation are based on the representation in THUNDER. Although all organizations represented in THUNDER are published (for the benefit of the viewer), only a subset of these currently receive their supplies from ELIST. This subset is specified in the user-created files which are read in by the ELIST and THUNDER federates upon initialization.

Figure 4 shows the hierarchy of object interactions, and the parameters of each interaction. The arrival interactions are arrivals of non-critical supplies, whereas the resupply interactions are used to track arrivals of critical resources. Of the types of supply arrival interactions, Equipment_Arv and AC_Arv are directed to particular organizations, whereas the remainder are general supply arrivals, in that the supplies are distributed to the appropriate units within THUNDER.

The Federation Executive, ELIST model and federate, and THUNDER model and federate are each run on a Sun Sparc Station. The Viewer/Controller federate is currently executed on a PC running Windows 95.

3.1 ELIST Federate

The ELIST federate consists of C++ code written using the HFC library, plus the legacy ELIST model (version 7.2). In order to allow the federate to regulate the running of ELIST, it was necessary to make a few modifications to ELIST. The original ELIST model was operated by a user through a graphical user interface (GUI); for WLTAE it was necessary for the model to be operable in an automated fashion. To allow ELIST to be operated in this mode, ELIST was modified by MTMC-TEA to read a control file. By appending lines to this control file, the ELIST federate is able to have ELIST run to a specified day and then pause until further directives are added to the control file. Additionally, several model parameters can be dynamically modified using this control file; currently WLTAE takes advantage of the ability to modify port throughput to reflect damages inflicted in THUNDER warfighting.

The ELIST federate incorporates ELIST results, which are output after each time step, by reading the ELIST output file. This file describes information about supply arrivals. To reflect these arrivals, the ELIST federate creates the appropriate arrival or resupply interactions.

The ELIST federate internally tracks the supplies that have arrived for each organization. When supplies for each organization reach the required levels, ELIST deploys the organization by toggling its deploy_status attribute. Upon receiving a Supply_Info_Request interaction from the Viewer/Controller, federate, ELIST "replies" by sending a Supply_Info interaction containing details about the supplies held by an organization.

On each time step, the ELIST federate reads the ELIST arrivals file, which describes the deliveries which arrived at their destinations. The federate then generates supply arrival interactions to reflect these deliveries.

3.2 THUNDER Federate

The THUNDER federate consists of C++ code written using the HFC library, plus the legacy THUNDER simulation (version 6.4). The original THUNDER simulation had been modified by LMI for the non-HLA link so that it can be run one step at a time. The simulation was further modified this year so that it appends to its output files after each time step, rather than after the completion of the entire simulation.

On each time step, the THUNDER federate reads the THUNDER output file which describes the position of each organization; the federate updates these attributes of the respective federation objects. This file also describes the current forward line of troops (FLOT); the

THUNDER federate publishes a FLOT_Spec interaction. On each time step the THUNDER federate also reads the THUNDER output file which describes the status of each installation; the federate then updates the appropriate attributes of the installation objects.

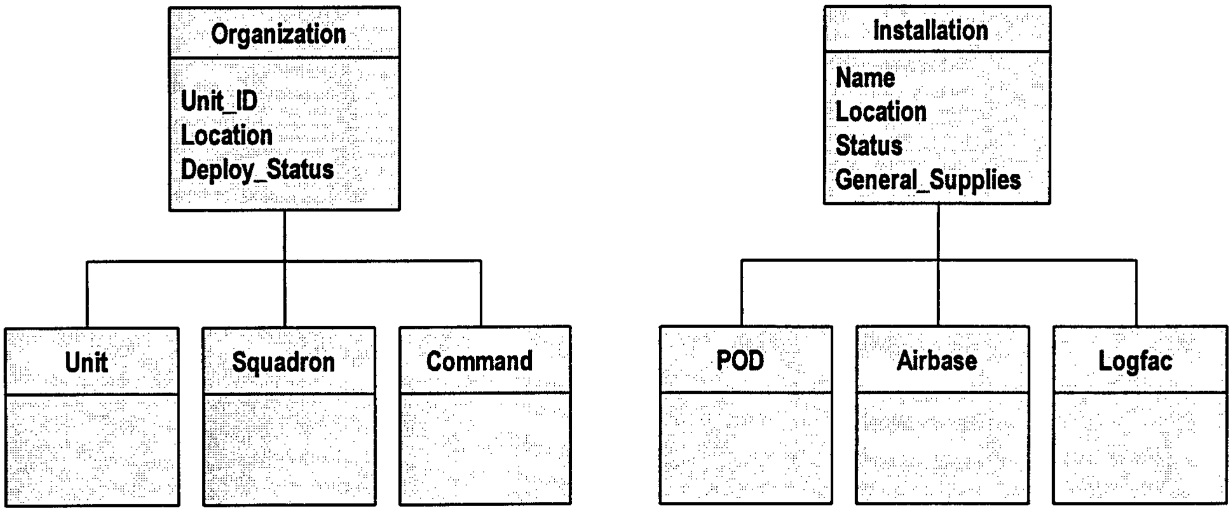

Figure 3 WLTAE Object Classes

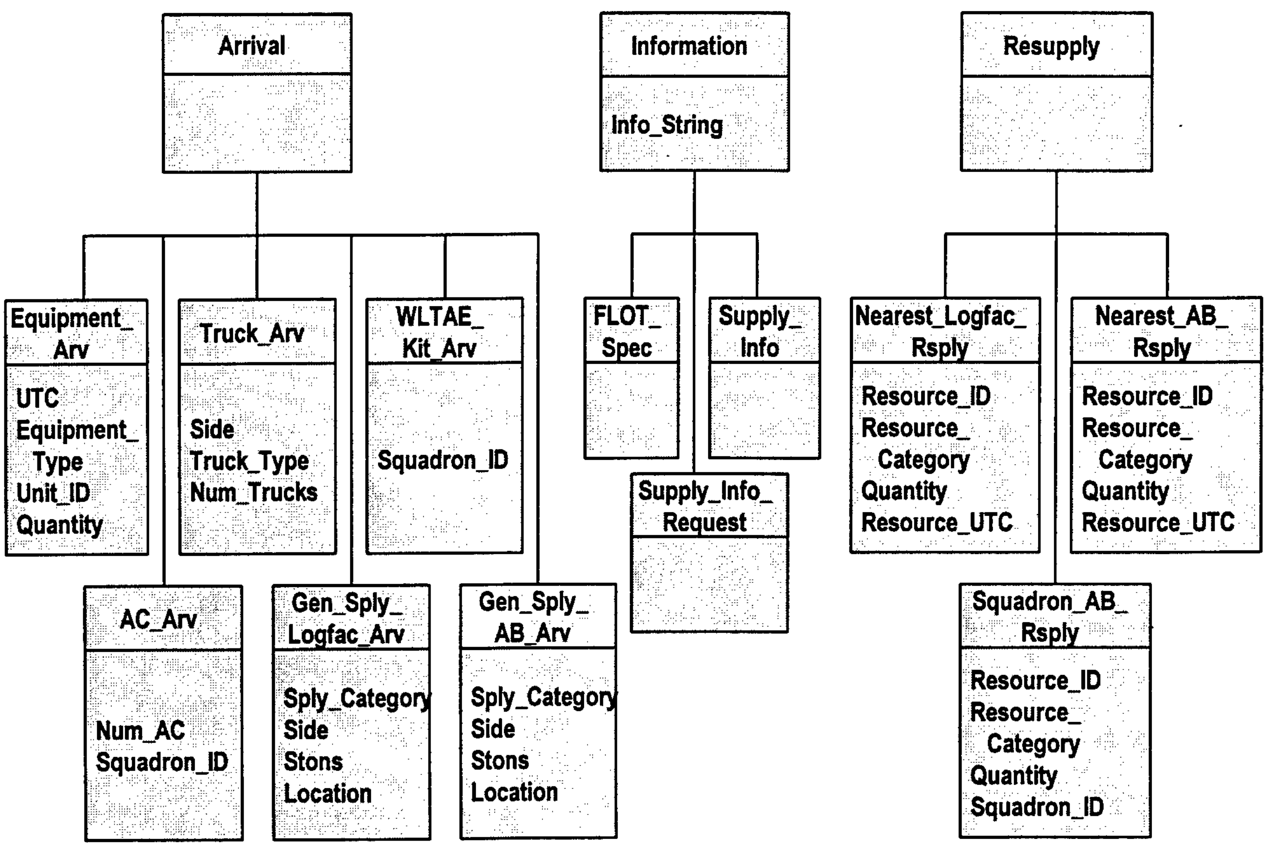

Figure 4 WLTAE Interaction Classes

Upon receiving arrival or resupply interactions, THUNDER appends to the "supply arrivals file" which is read by THUNDER at each time step.

3.3 Viewer/Controller Federate

The WLTAE Viewer was developed to provide an integrated display environment for warfighting and logistics information, to serve as an analysis tool, provide data logging for the WLTAE Federation, and provide a standalone playback capability. The Viewer can be used by CINCs and their staff to answer fundamental questions, such as: how is the warfight progressing, what are the consequences of attack or damage to the logistics infrastructure, what are the projected arrival times of equipment, or is a unit missing a key component.

3.3.1 Design: A modular design approach was used for the Viewer. It is composed of two components: the display/graphical user interface portion and the Viewer federate. The display portion of the Viewer provides the user with federation control capabilities and status information, a standalone playback capability, an easy to use graphical user interface, and access to various analysis capabilities. The Viewer federate subscribes to the various federation attributes published by the ELIST and Thunder simulation federates. The Display component and the Viewer federate communicate over a TCP/IP streamed data socket. This allows the two components to reside on separate computers and communicate over the Internet or a standard telephone line using a Slip or RAS connection. This provides a low cost connectivity between the WLTAE Warfighting and Logistics simulations, and remote users. To have access to the full capabilities of WLTAE, a remote user would need only a PC with Windows 95 or Windows NT and a modem.

A relational database was chosen to archive federation information, provide a playback capability, and a query capability. A relational database provided the most flexibility in storing and accessing large quantities of data.

3.3.2 Tools: Rapid Application Development (RAD) tools and the HFC library were used to build the WLTAE Viewer/Controller. Microsoft Visual Basic was used to develop the Display component of the Viewer/Controller. The GUI and database tools in Visual Basic greatly reduced the time necessary to create this component. The GUI design environment of MS Access was used extensively to prototype queries for the Viewer.

3.3.3 Environment: The WLTAE Viewer was installed and tested on PCs running Windows 95 and Windows NT 4.0 operating over a 16 Mbs token-ring network. The ELIST and THUNDER federates were installed on a Sun Sparc Station operating on a separate 10 Mbs Ethernet network connected by a Network Bridge to the token-ring network segment. The RTI and Federation executives were also run on Sun Sparc Stations.

4. Test Scenario and User Interface

The test scenario used was a war in the Middle East. Iraq invades Kuwait and Saudi Arabia, the United States reacts by halting invaders, building up forces in the theater, and then counter attacking. The Allied ground forces consisted of one Kuwait division, one Saudi division, five 1/3 U.S. Army divisions, and two Marine fly-in-echelons. The air units consisted of 14 Air Force tactical fighter squadrons, two Marine Air tactical fighter squadrons, and eight Navy tactical fighter squadrons.

The information required to construct this scenario consisted of three sets of data. The TPFDD holding the U.S. deployment data, the warfight parameters along with the order of battle for the Iraqi and allied forces in the THUNDER data files, and the in-theater transportation and host nation support details in the ELIST data files.

The first test case was a short-warning scenario. Five days of warning were assumed before an Iraqi invasion of Kuwait and Saudi Arabia.

4.1 Results

The results of the short-warning scenario indicate that the enemy overruns the allied forces. This is because many of the units assumed to be fighting at the front had been delayed as a result of missing key components. Figure 5 shows the Viewer main display and situation map on day seven of the warfight. The Iraqi forces have pushed though Kuwait and are deep into Saudi Arabia as shown by the FLOT line displayed in magenta. The yellow circles indicate U.S. forces that have not been deployed because of key supplies not being delivered by that time.

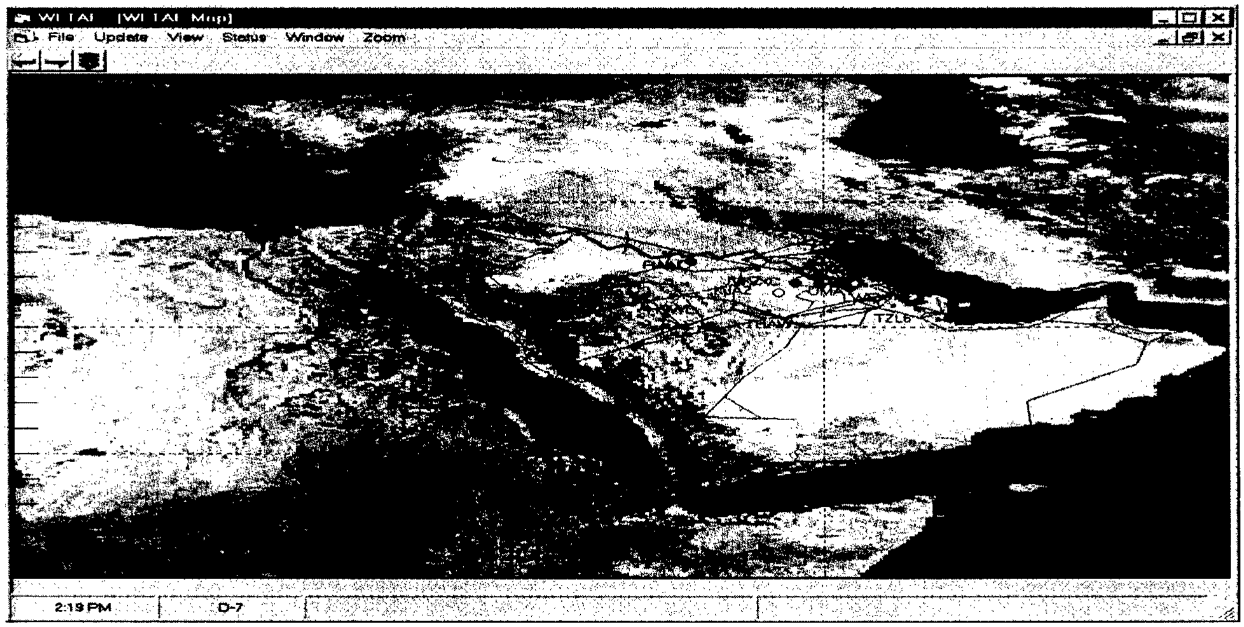

Figure 5 Viewer Main display and Situation Map on Day 7 of the Warfight

4.2 User Interface

By using the Viewer it is possible to drill down into the detail and discover problems that contributed to the late deployment of U.S. forces. Figure 6 shows the equipment status for the 1/1 Cavalry Division Kuwait on day seven of the warfight. This division has not been deployed because it is missing critical heavy equipment transporters (HET) moveable tonnage even though all its personnel are in place.

D-7 1/1CAV KUWAIT

Commodity	Expected Amt	% Complete
Ammunition Containerized	24.8	100
Containerized	414.8	100
HET Movable Tonnage	15996.3	1
Not Containerized	352.0	100
Organic Tonnage	12846.2	82
Personnel	4834.0	100

Figure 6 Equipment Status for the 1/1 Cavalry Division on Day 7 of the Warfight

The Viewer provides the capability to search for matching Unit Type Codes (UTCs) in the theater. The UTC describes the generic equipment that is contained in the ULN. A CINC could use this search capability to locate and redirect supplies to organizations with a more critical need for that equipment. Figure 7 shows the capability of the Viewer to query all of the supplies being delivered into the theater. By double clicking on an equipment type, the CINC can find the location and expected delivery for all the matching UTCs in the theater that might be considered for substitution. Figure 8 shows an example query for all Apache attack helicopters in the theater, where they are being sent and when they are expected to arrive. Alternatively, the CINC could decide the missing equipment is not combat-critical and could deploy the Unit as it is currently configured.

5. Future Plans

Future plans are to continue to develop the WLTAE federation and add additional user functionality. The addition of Naval warfighting and logistics models and databases are required to make WLTAE truly joint. There is also interest in extending the logistics component of WLTAE back to CONUS. A proposal to implement this extension by combining WLTAE with the Argonne Distributed Intelligent Agents for Logistics (DIAL) is described in a companion paper being presented at this conference [3].

As described in the introduction, the near term goal is to make WLTAE into a mission planning tool for the CINC and his staff. In this WLTAE is intended to allow the CINC to ask a variety of questions. Typical questions

WLTAE Equipment

UTC	Description	#UTCs
3E322	HHC DIV AVN BDE HVY	1
3E666	HHC DIV AVN BDE IDL	2
2EUTT	HHC HVY DIV BDE ARMOR	4
NBF22	HHC SUPPORT GROUP CORPS	2
0W322	HHC AIR ASSAULT BRIGADE	6
0HP66	HHC AIR ASSAULT DIVISION	2
4LRNN	HHC COMBAT ENGINEER GROUP	2
0LTTT	HHC INF DIV MECH BDE	2
NED77	HHC MMC SPT CMD AASLT DIV	2
N21VV	HHD CORPS SUPPORT BN	4
42B77	HHD ENGINEER BRIGADE	2
GC722	HHD CHEMICAL BATTALION	2
Q2F77	HHD MP BATTALION	2
2T222	HHT ACR	2
3PLFP	HMH (16 CH-53E)/MPS FIE	2
3PLAP	HMH (8 CH-53D)/MPS FIE	2
3PUAP	HMLA (18 AH-1/9 UH-1)/MPS FIE	2
3PNAP	HMM (12 CH-46)/MPS FIE	4
9HEEP	HQ BTY, ARTY BN/MPS FIE	2

Figure 7 Example Equipment List

ATTACK HEL BN AH 64

UTC	Description	ULNID	PODNAME	CDay
3RF77	ATTACK HEL BN AH 64	TANAC	TZL4	C031
		TANAP	TZL4	C030
		TAN3C	TZL4	C037
		TAN3P	TZL4	C036
		TAPFC	TZL4	C037
		TAPFP	TZL4	C036

Figure 8 Example Attack Helicopter Query

might be a series of inquiries such as:

- How is the warfight progressing?
  - Where is the enemy advancing, where am I advancing?
  - How do actual consumption rates of supplies compare to planned rates?
  - Can the enemy attack/damage my logistics infrastructure?
- What is the status of my combat units?
  - What are their combat readiness levels?
  - Is a unit missing key ULN components?
    - Where are the missing ULNs and when will they arrive?
    - Can I deploy the unit without the missing components?
    - Are there substitute ULNs elsewhere in the theater than can be transferred to complete this unit?
- Can I maintain my warfighting tempo?
  - What is my sustained operational capability?
  - If supplies slow or stop temporarily, can I recover without losing tempo?

From the types of questions that might be asked, it is clear that visibility into unit status and the ability to drill down to details is essential. The Viewer/Controller provides this initial capability. Equally important is the ability to translate these changes back into the TPFDD and the warfight. Modifications to the Viewer/Controller will be made that allow the CINC to redirect the flow of supplies into the theater (i.e. modify the destinations of items to be delivered by ELIST) or deploy units to THUNDER for combat without the full set of ULNs being delivered.

Acknowledgements

This WLTAE development was funded under the DARPA Advanced Logistics Program. We would like to thank the Program Manager, Todd Carrico, for his support of this effort to integrate warfighting and logistics models. We would also like to thank Military Transportation Management Command-Transportation engineering Agency for making ELIST available and Air Force Studies and Analysis Agency for making THUNDER available to the WLTAE project.

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